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TECHNICAL REPORT ECOM-90705-18



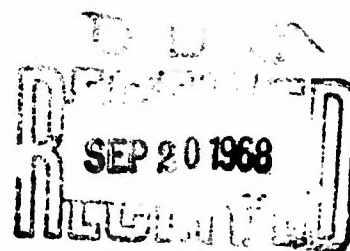
**RESEARCH AND DEVELOPMENT
INTRINSIC RELIABILITY
SUBMINIATURE CERAMIC CAPACITORS**

INTERIM PROGRESS REPORT

BY

T. I. PROKOPOWICZ and A. R. VASKAS

AUGUST 1968



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CONTRACT NO. DA-36-039-SC-90705

SPRAGUE ELECTRIC COMPANY

NORTH ADAMS, MASSACHUSETTS

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RESEARCH AND DEVELOPMENT

INTRINSIC RELIABILITY

SUBMINIATURE CERAMIC CAPACITORS

INTERIM PROGRESS REPORT

1 August 1967 - 31 January 1968

Report No. 18

Contract No. DA-36-039-SC-90705
D. A. Project No. 1P6 22001 A 057

Prepared By:

T. I. PROKOPOWICZ AND A. R. VASKAS

SPRAGUE ELECTRIC COMPANY

North Adams, Massachusetts

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ABSTRACT

The 20,000-hour, voltage/temperature life test matrix, which involved the 0.01 μF C67 Case Size I MONOLYTHIC® capacitor, is discussed. Frequency histograms of all leakage current data and Weibull determinations of failure rates for some of the test conditions are included. In addition, the criteria which determined short-life capacitors during testing are presented, as well as a comparison of calculated assured life times with the times to actual life test failure. Finally, the schedule and conditions for a second voltage/temperature life test matrix using the 0.033 μF C67 device are briefly summarized.

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SECTION 1

INTRODUCTION

The purpose of this contract is to carry out research work involving investigations leading to approaches to the attainment of high reliability in subminiature ceramic capacitors and the determination of failure rate as a function of voltage and temperature.

In particular, this involves the following:

- (1) Construction of a model or theory to predict failure mechanisms and failure rates as a function of voltage and temperature.
- (2) Development and evaluation of a short-term test to eliminate early failures effectively without shortening the time to the wearout mode of failure.
- (3) A determination of the failure rate as a function of voltage and temperature through large-scale life testing. From the data thus obtained, derating curves will be derived and overall failure rates for operating conditions will be estimated. The theory developed will be critically examined and refinements made.
- (4) Compilation of quarterly progress reports in accordance with Signal Corps Technical Requirements No. SCL-2101N, dated 14 July 1961.
- (5) Compilation of a final report in accordance with Signal Corps Technical Requirements No. SCL-2101N, dated 14 July 1961.

SECTION 2

FACTUAL DATA

2.1 Construction of C67 Case Size I MONOLYTHIC® Capacitors

The 0.01 μ F and 0.033 μ F C67 Case Size I MONOLYTHIC® Capacitors are constructed with stacked ceramic dielectric layers 0.0025 and 0.001 inches thick, respectively. The layers, which are bonded to one another by high-temperature sintering and electrically connected in parallel, are composed of barium titanate which has a dielectric constant of approximately 2000 and a stability of +10%, -15% between -55°C and +125°C. The capacitors are enclosed in tubular cases 0.25 inches long with a 0.095 inch diameter.

2.2 Selection of Long-Life Capacitors of the Improved Version

This experiment, designed to establish a procedure for selecting long-life capacitors of the improved version, began during the eighth quarter of this contract and is still in progress. The basic goal is to demonstrate that the life which a capacitor loses during a brief period of accelerated testing can be regained by applying a DC voltage of opposite polarity for a given time. Progress on this project has been described in Interim Reports Nos. 8, 9, 13 and 17. Because of a test equipment failure, there are no new data to present at this time. Following the necessary repairs, work on this equipment will resume.

2.3 Completion of 20,000 Hours of the First Voltage/Temperature Life Test Matrix2.3.1 Introduction

The 0.01 μ F C67 Case Size I MONOLYTHIC® capacitor, whose general construction is described in Section 2.1, was selected for this matrix. Test units were obtained from Lot 6S-9205. Figure 1 shows the life test schedule, including the preliminary two-step burn-in. Table I lists the voltage/temperature conditions for the life test.

The design of the life test is such that its continuance until 50% or more of the capacitors fail will allow statistical analysis of the test data for correlations among unit-life times, voltages and temperatures. In addition, the rate of resistance change after degradation begins can be determined as a function of both voltage and temperature.

2.3.2 Failure Prediction

The leakage current data obtained for Steps A and B of the burn-in were used to establish the following criteria which determined short-lived capacitors after 10,000 hours of life testing. A unit was rejected if:

- (A) Its leakage current after 1, 49, 51 or 100 hours of burn-in exceeded $0.1 \mu\text{A}$ (Step A or Step B).
- (B) The ratio of the 49th to 1st hour leakage currents exceeded 10 (Step A).
- (C) The ratio of the 100th to 51st hour leakage currents exceeded 10 (Step B).

Histograms of the burn-in test data were presented in the Fourteenth Interim Progress Report.

2.3.3 Life Test Matrix Data

One half of the capacitors in each voltage/temperature group were tested under negative potential as in Step B of the burn-in because experience has shown that 50% of the units screened by the procedures in Steps A and B of the burn-in can expect placement in a circuit whose applied DC voltage is negative.

Figures 2 through 10 are histograms of the leakage current data obtained after 10,000, 15,000 and 20,000 hours of life testing. There was significantly greater leakage current increase with time for units at the three 150°C conditions than for devices at the other test conditions. Actual life test failures; i. e., those not predicted by the criteria based on burn-in data, are listed in Table II. The greater number of these failures occurred at the two severest 150°C test conditions. There were two criteria for actual life test failures:

- (A) The unit was not rejected by the burn-in criteria.
- (B) The unit exhibited an IR value below $500 \text{ M}\Omega$ (MIL-C-39014).

2.3.4 Assured Life Times

The assured life time (ALT) is the guaranteed period over which the capacitor can survive a given voltage/temperature condition. The ALT values listed in Table II were based on the 200V/150°C burn-in condition and calculated using the following generalized equation:

$$t_1 = t_2 \left[\frac{E_1}{E_2} \right]^{2.7} \exp \left[\left(\frac{0.90}{k} \right) \left(\frac{1}{T_1} - \frac{1}{T_2} \right) \right] \quad (1)$$

where

t_1, t_2 = performance¹ times under conditions 1 and 2, respectively.

E_1, E_2 = volts/mil for conditions 1 and 2, respectively.

k = Boltzman's constant

T_1, T_2 = temperature conditions 1 and 2, respectively.

Although derived from data pertaining to time-to-onset-of-degradation as a function of voltage and temperature, this equation was extended to allow calculation of ALT's and currently provides the best approximations of ALT values.

The validity of the rejection criteria as well as the level of overall life test performance can be gauged by comparing the assured life times with the times to earliest failures given in Table II. For example, the times to earliest failures for the 200V/125°C, 100V/150°C and 200V/150°C conditions exceeded the assured life times by factors of 1.5 to 5. However, the initial failures for the 100V/125°C and 50V/150°C groups occurred before completion of their assured life times. The rejected unit in the 50V/150°C group had a 49th hour to 1st hour leakage current ratio of 9.2 compared to the failure criterion (Step A) ratio of 10, but the difference does not warrant revision of failure criteria. The two failures experienced at the 100V/125°C condition could not have been predicted by the failure criteria and are currently undergoing failure analysis.

There were no failures among the 50V/85°C, 100V/85°C and 25V/125°C groups. However, the assured life times for these conditions remain unverified because they exceed the 20,000-hour test period.

(1) Performance time is the length of time before which the units on test at a given condition experience an actual life test as defined in Paragraph 2.3.3.

2.3.4 Failure Rates

An attempt was made to determine failure rates for long-life capacitors tested for 20,000 hours. Only the 50V/150°C, 100V/150°C and 200V/150°C conditions provided the quantity and distribution of actual life test failures necessary for this purpose.

Figure 11 is a plot of the percentage of failures at readout time versus hours on test for each condition. The failures in the 50V/150°C group occurred at an almost constant rate, except for a slight rise after 1,000 hours, while the percentage of failures at readout for the other groups increased with time. These general conclusions were supported by a Weibull distribution study.

The Weibull distribution, originally used in fatigue analyses of ball-bearings, has become a standard technique for determining best-estimate failure rates for electronic components. The cumulative percentages of failure (Table III) versus test time were plotted on the specially-designed Weibull probability paper (Figure 12). From this graph, β , the shape parameter, and $-\ln \alpha$, the scale parameter, were estimated from the outer left- and right-hand scales, respectively.

The shape parameter, β , is the gauge of data behavior. For $\beta > 1$, the failure rate increases with time, for $\beta < 1$, the rate decreases with time, and for $\beta = 1$, it is constant and follows the exponential failure rate. In Figure 6, the β value for the 100V/150°C and 200V/150°C conditions are 1.1 while the β value for the 50V/150°C condition equals 1.0.

The instantaneous failure rate at any time is calculated by the following formula:

$$Z(t) = \left(\beta / \alpha (t)^{\beta-1} \right) \left(10^5 \right) \quad (2)$$

where

$Z(t)$ = instantaneous failure rate at time t

β = shape parameter

α = scale parameter

t = time

10^5 = conversion factor for failure rate expressed as %/1000 hours.

Instantaneous failure rates at readout times were obtained for each of the three conditions and plotted against time (Figure 13) to determine projected failure rates:

50V/150°C. The failure rate is nearly constant with time. A reading of the inner left and bottom scales indicates that 50% of the units in this group will fail at approximately 80,000 hours, demonstrating a best-estimate constant failure rate of 0.985%/1,000 hours.

100V/150°C. The failure rate increases with time as indicated in Figure 11. Half the units will fail at 15,000 hours, demonstrating a best-estimate failure rate of 4.9%/1,000 hours.

200V/150°C. The failure rate increases with time. With 50% of the capacitors having failed at 20,000 hours, the best-estimate failure rate is 24%/1,000 hours for this condition.

2.4 Capacitors for Second Voltage/Temperature Life Test Matrix

Fabrication of the 0.033 μ F C67 Case Size I MONOLYTHIC® capacitors has been completed. The units, constructed with stacked ceramic dielectric layers 0.001 inches thick, are currently undergoing a voltage/temperature life test matrix. The test schedule, including the two step burn-in, is given as Figure 14; Table IV lists the life test conditions.

The tentative rating of the 0.033 μ F device is 25WVDC at 85°C with a 50% voltage derating at 125°C. The 25WVDC value was selected so that TCVC Characteristics BX could be met as required by MIL-C-11015 and MIL-C-39014.

The conditions for burn-in Steps A and B were calculated with Equation (1) and are such that 4,000 hours of failure-free performance can be attained at 25V and 125°C. There are four failure criteria at burn-in:

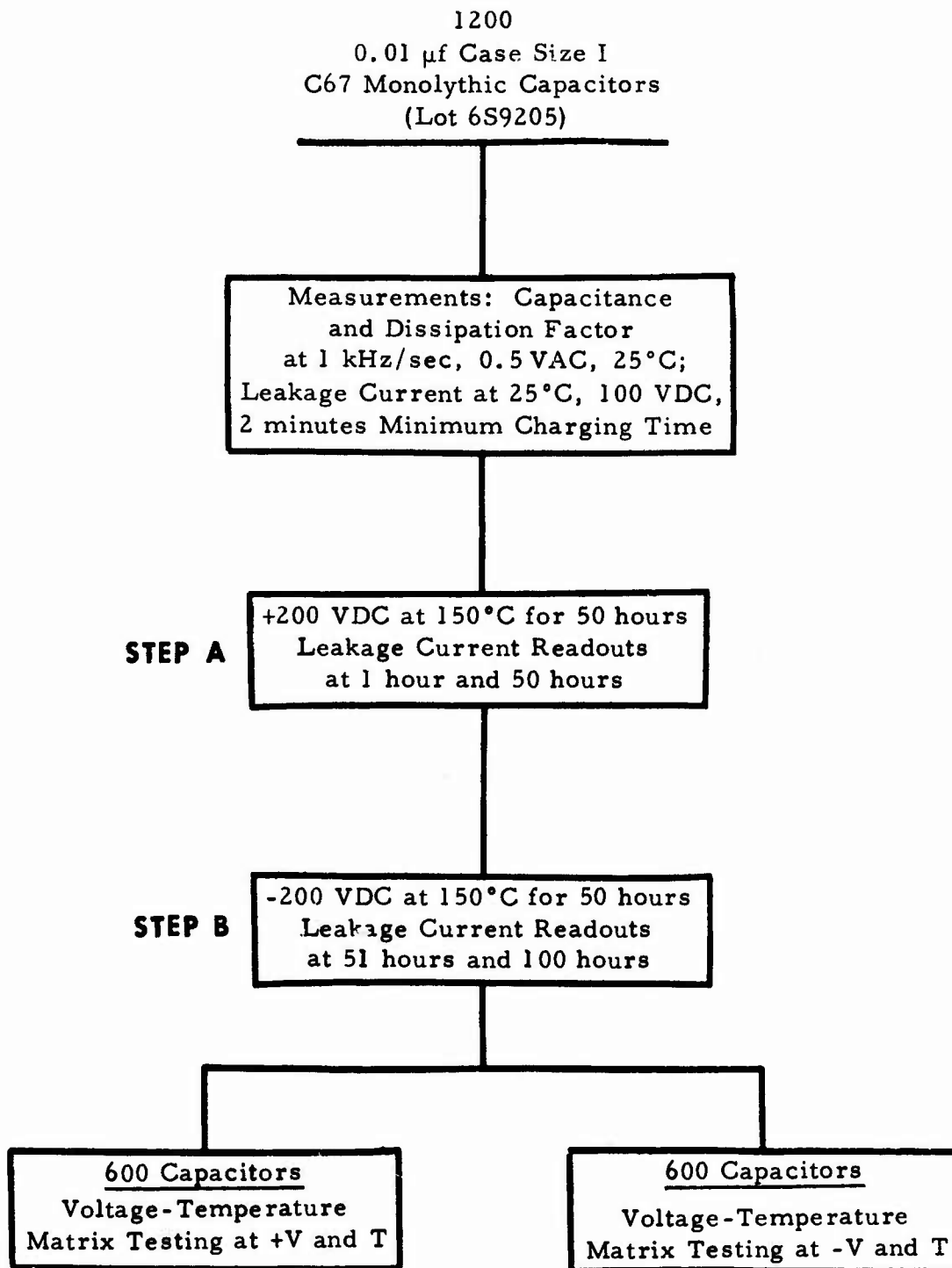
- (A) $+I_{23}/+I_1$ greater than 5 or less than 0.2 μ A.
- (B) $-I_{23}/-I_1$ greater than 5 or less than 0.2 μ A.
- (C) I_1, I_{23} greater than 0.1 μ A.

The capacitors which did not meet these criteria were allowed to continue on test for information purposes. Analysis of the test data may reveal the criteria to be inappropriate or the screening formula to require modification.

SECTION 3

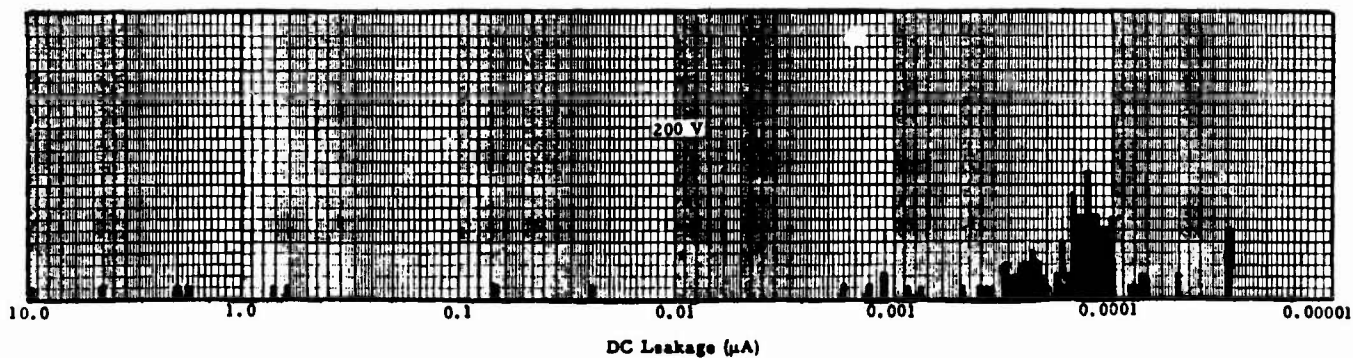
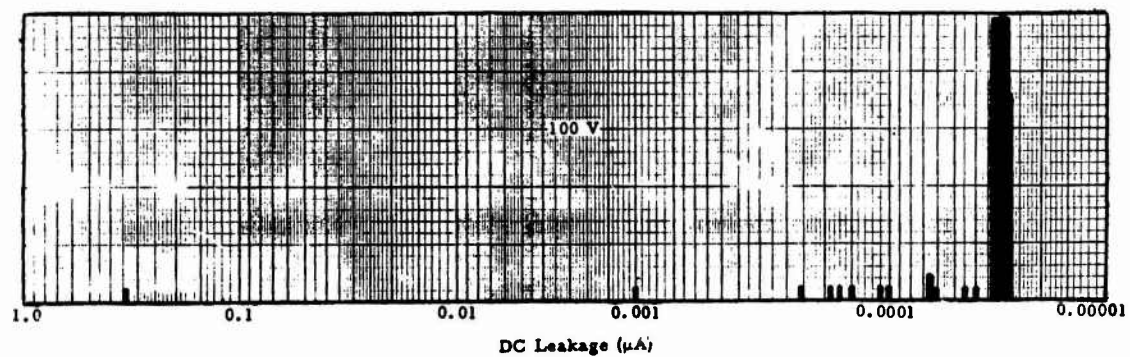
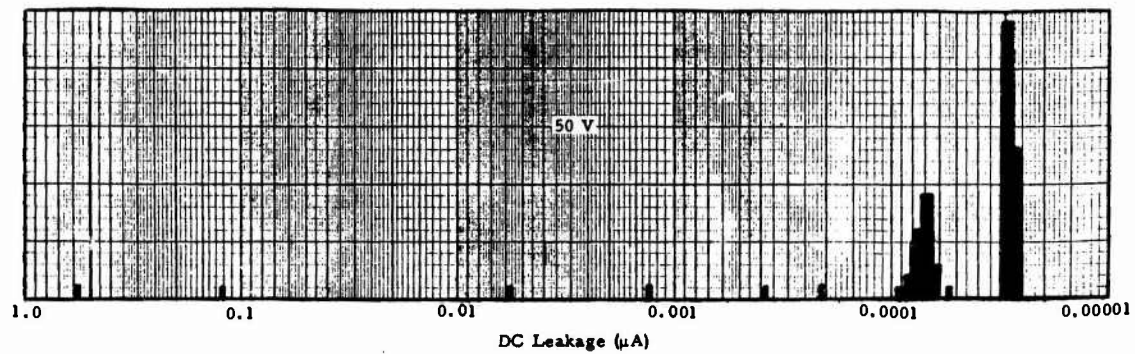
CONCLUSIONS

- (1) Histograms of the leakage current data obtained for the 0.01 μ F C67 capacitors after 10,000, 15,000 and 20,000 hours of life testing showed significantly greater leakage current increase with time for units at the three 150°C conditions than for devices at the other test conditions. A plot of the percentage of failures at readout time versus hours-on-test for these conditions indicated that failures in the 50V/150°C group occurred at an almost constant rate while the percentage of failures at readout for the other groups increased with time. These general conclusions were supported by a Weibull distribution study.
- (2) The Weibull analysis of the data for the three 150°C test conditions yielded best-estimate failure rates of 0.985%/1,000 hours for the 50V/150°C condition, 4.9%/1,000 hours for the 100V/150°C condition, and 24%/1,000 hours for the 200V/150°C condition. Failure rates could not be determined for the other test conditions because their data did not provide the quantity and distribution of actual life test failures necessary for this purpose.
- (3) The behavior of the 100V/150°C and 200V/150°C groups suggests that extreme voltage/temperature combinations are in themselves a possible cause of actual life test failures with time and that, consequently, the observed increasing failure rate may not be representative of the true failure distribution.



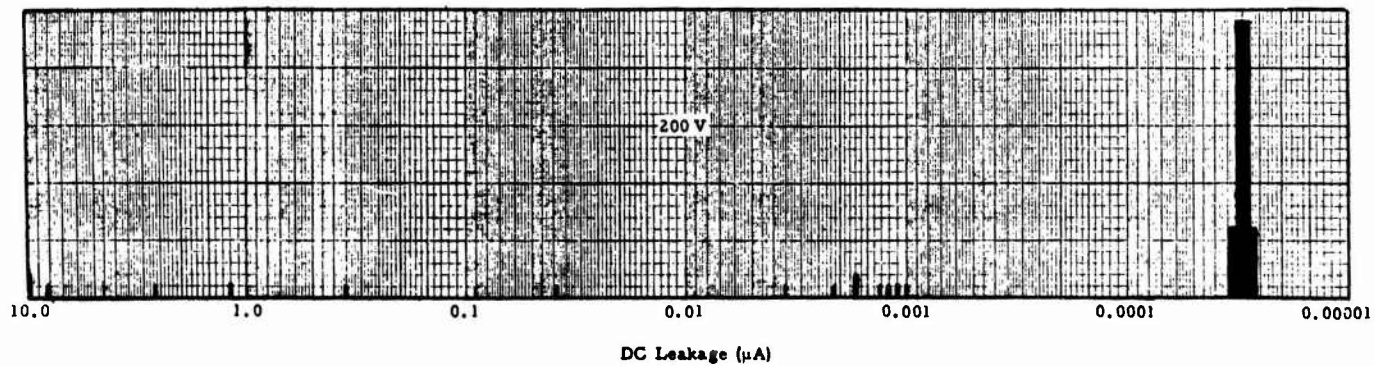
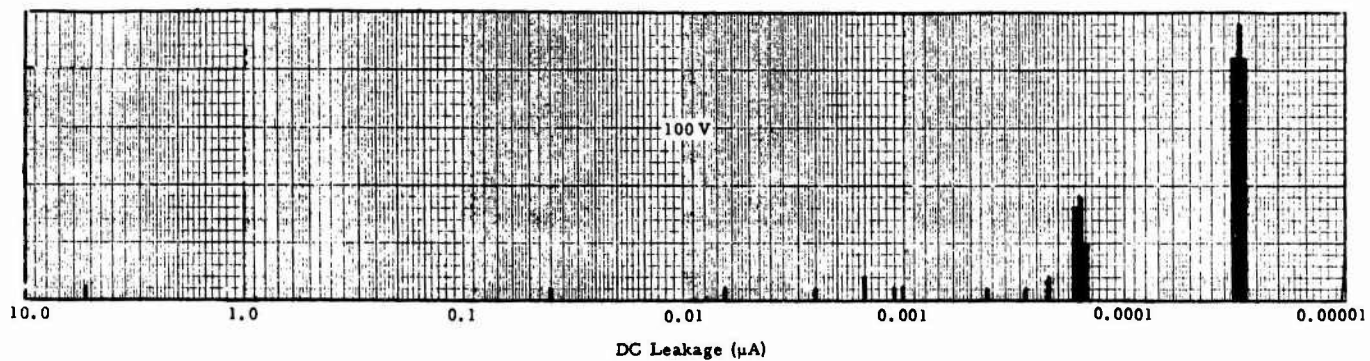
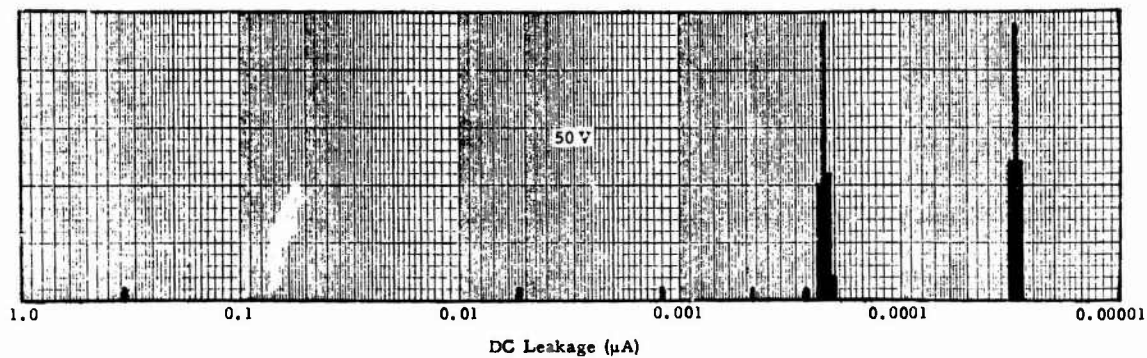
OUTLINE OF FIRST LIFE TEST MATRIX

Figure 1



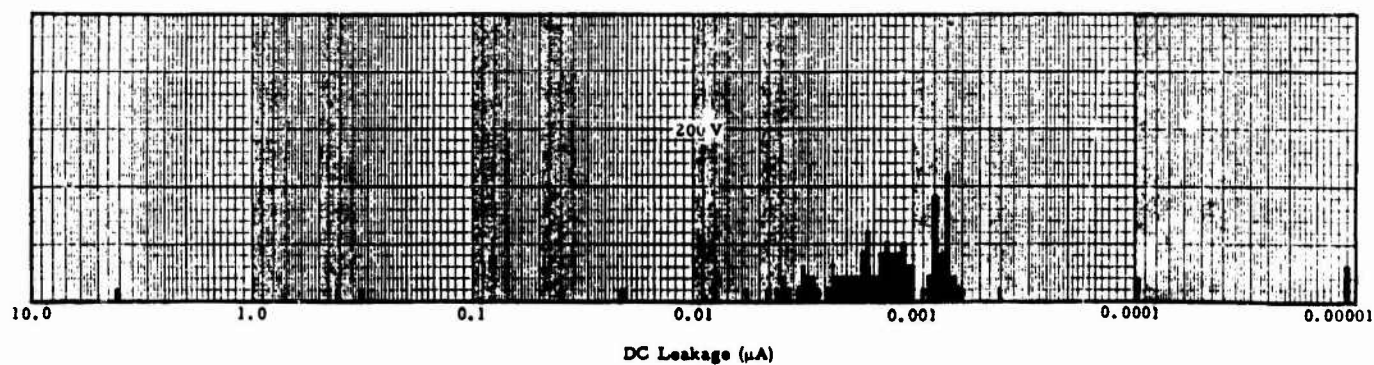
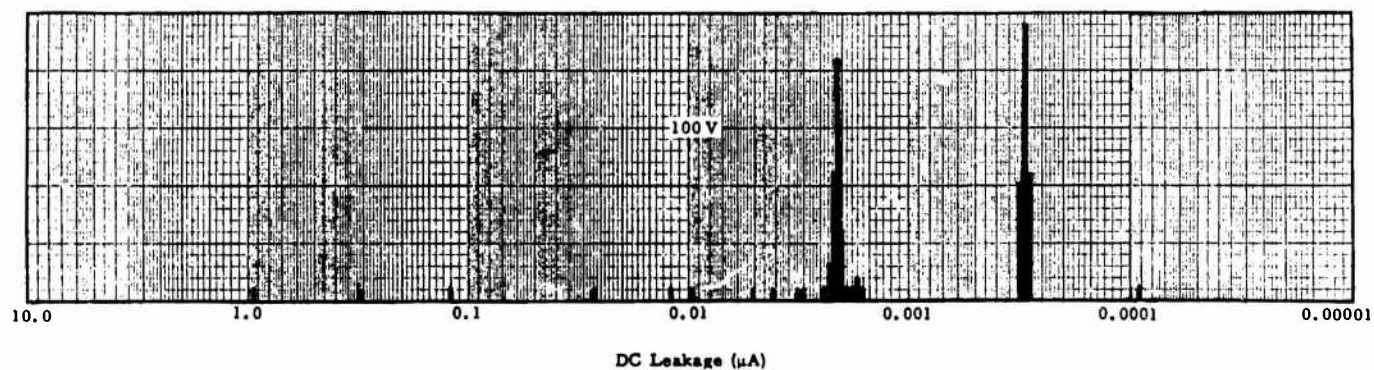
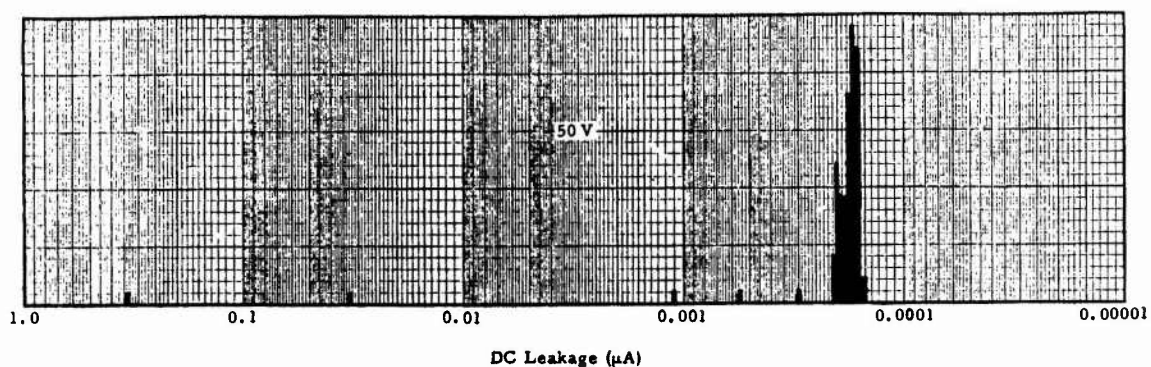
FREQUENCY DISTRIBUTION OF LEAKAGE CURRENT ON 85°C 10,000 HOUR LIFE TEST
FOR 0.01 μF C67 CASE SIZE I MONOLYTHIC CAPACITORS (LOT 659205)

Figure 2



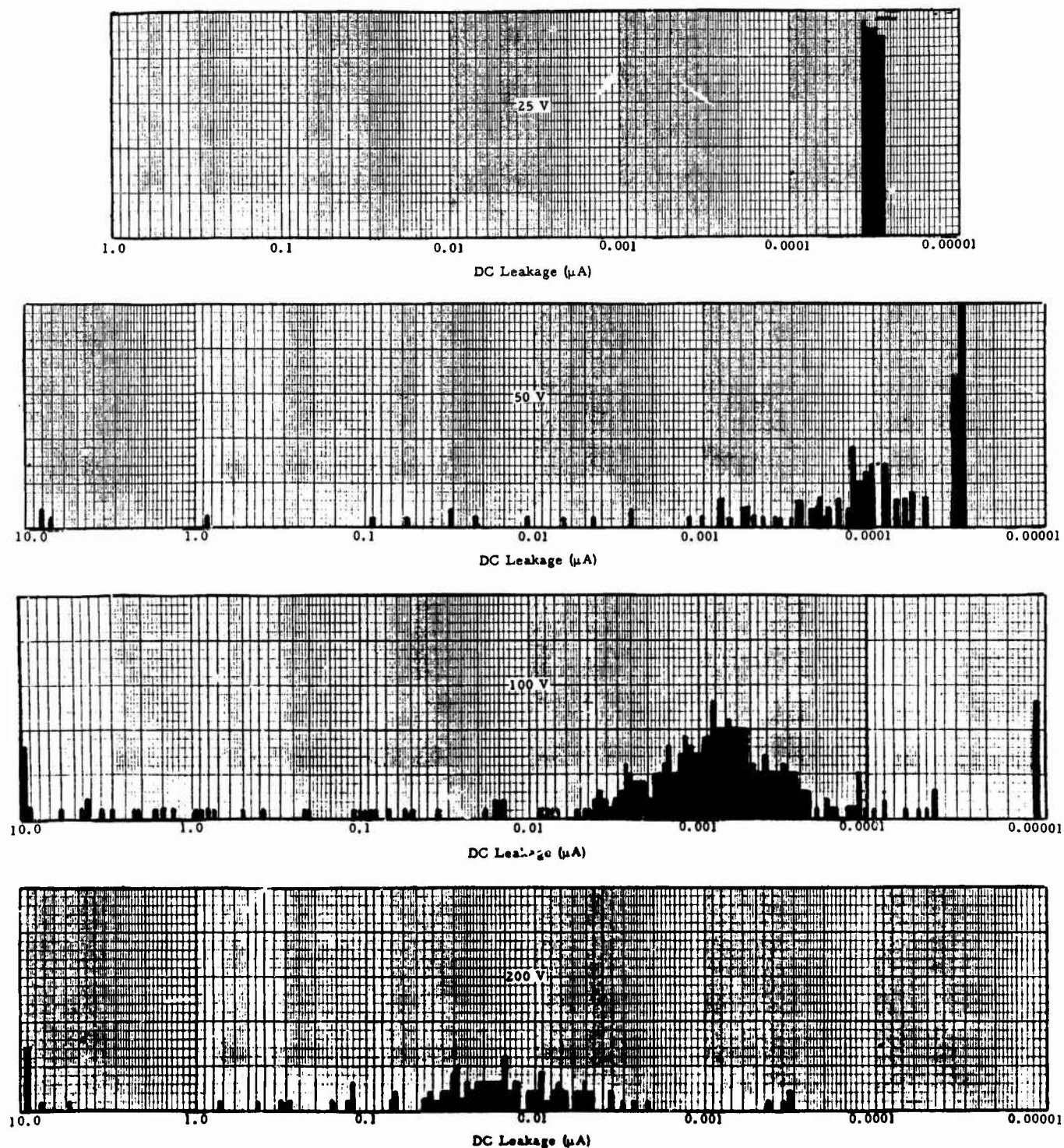
FREQUENCY DISTRIBUTION OF LEAKAGE CURRENT ON 85°C 15,000 HOUR LIFE TEST
FOR 0.01 μF C67 CASE SIZE I MONOLYTHIC CAPACITORS (LOT 6S9205)

Figure 3



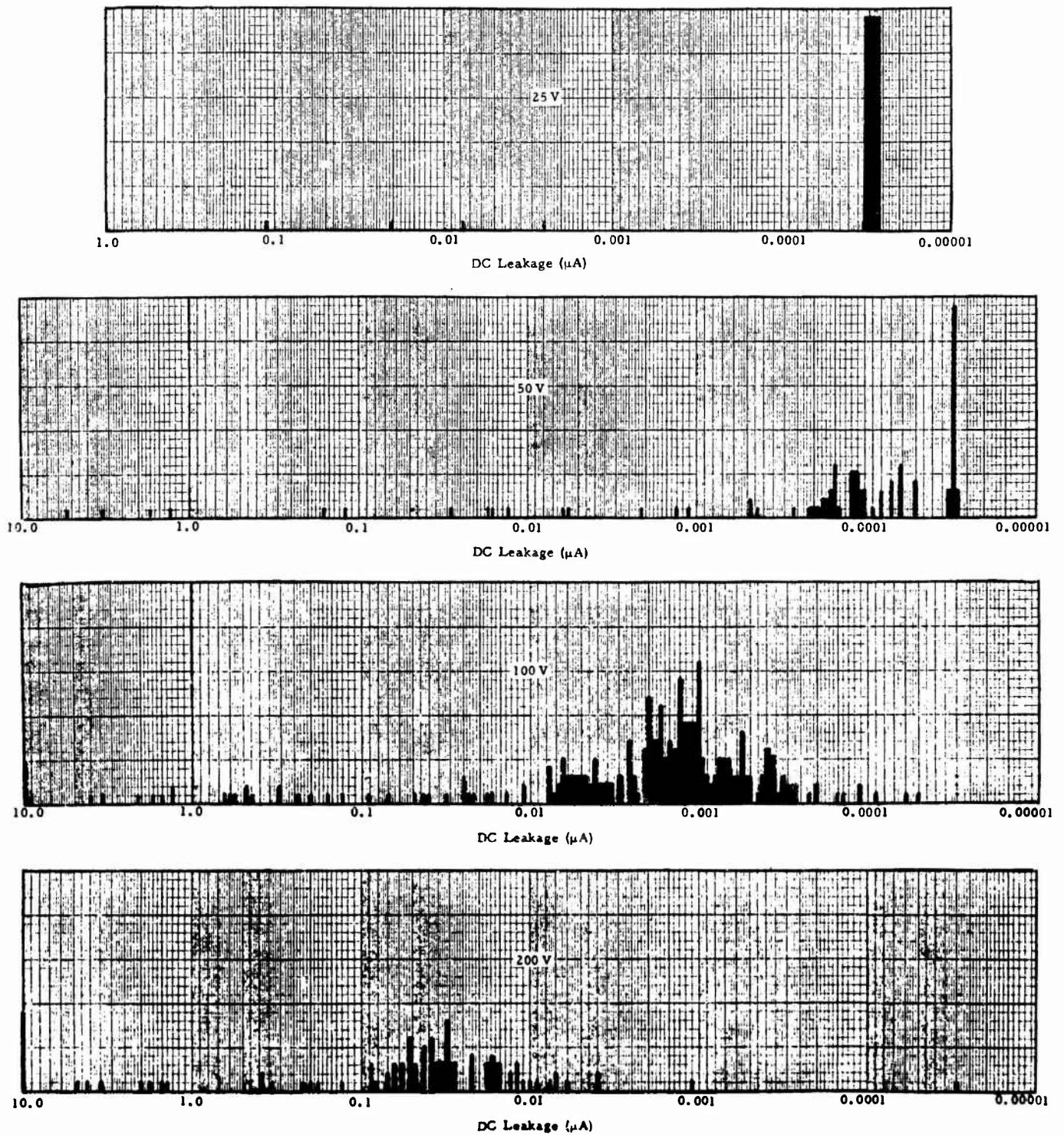
FREQUENCY DISTRIBUTION OF LEAKAGE CURRENT ON 85°C 20,000 HOUR LIFE TEST
FOR 0.01 μF C67 CASE SIZE 1 MONOLYTHIC CAPACITORS (LOT 6S9205)

Figure 4



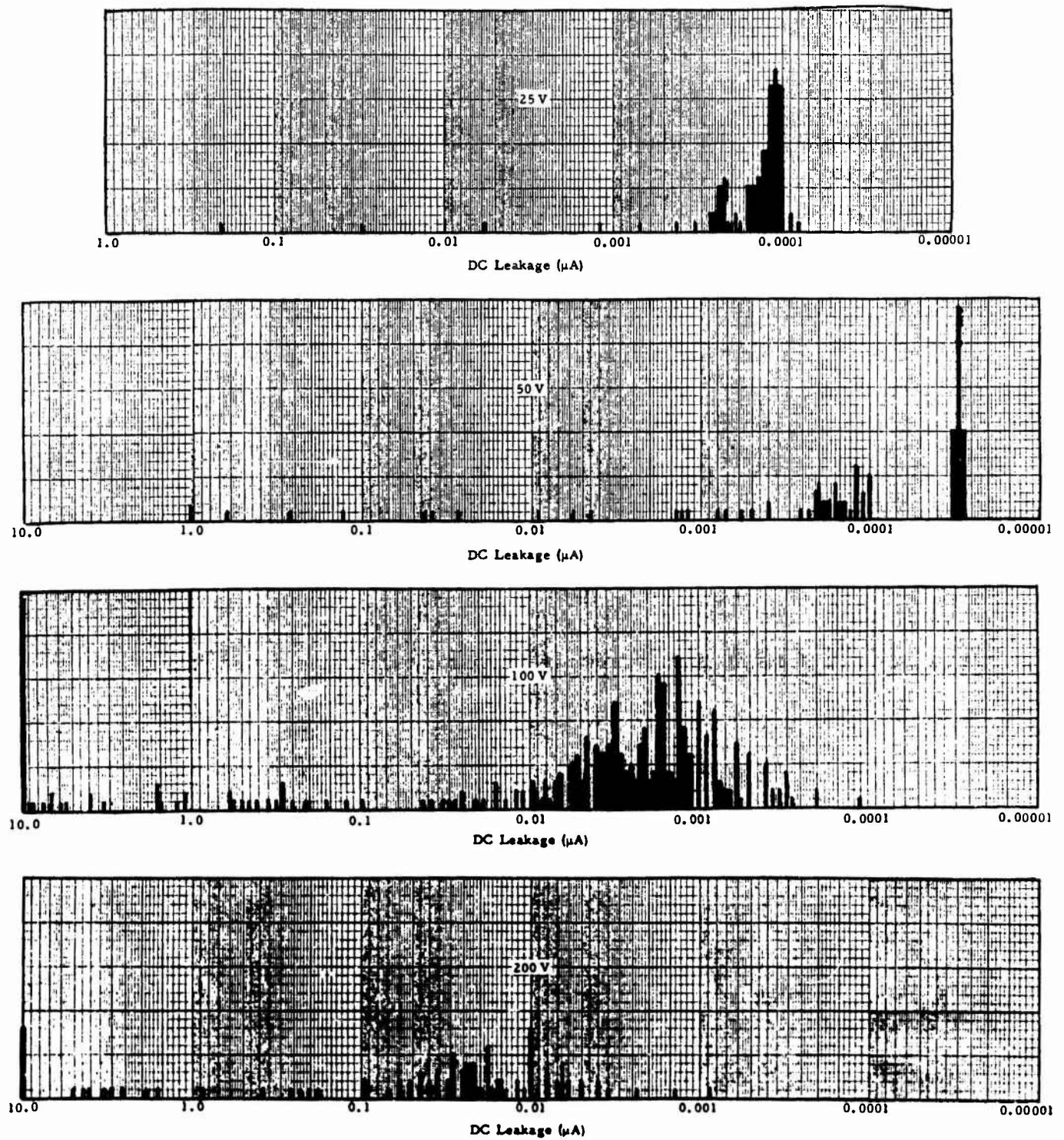
FREQUENCY DISTRIBUTION OF LEAKAGE CURRENT ON 125°C 10,000 HOUR LIFE TEST
FOR 0.01 μF C67 CASE SIZE I MONOLITHIC CAPACITORS (LOT 659205)

Figure 5



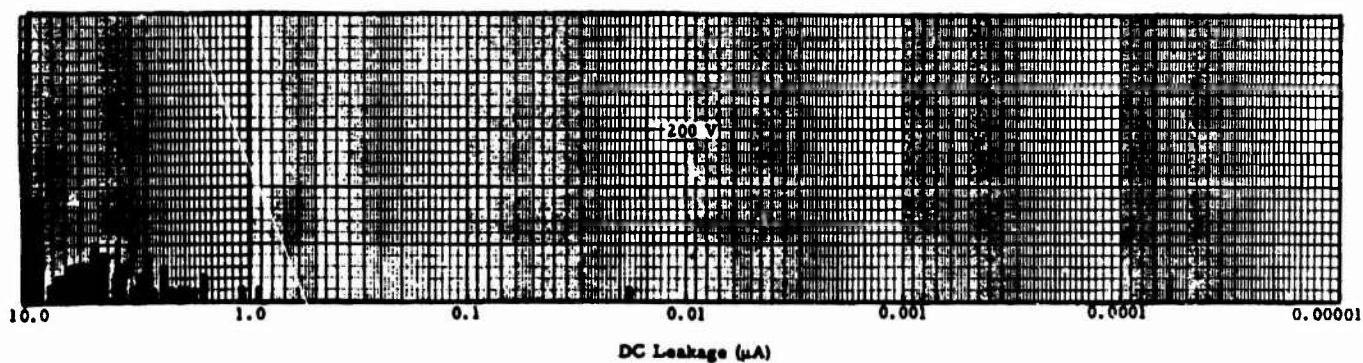
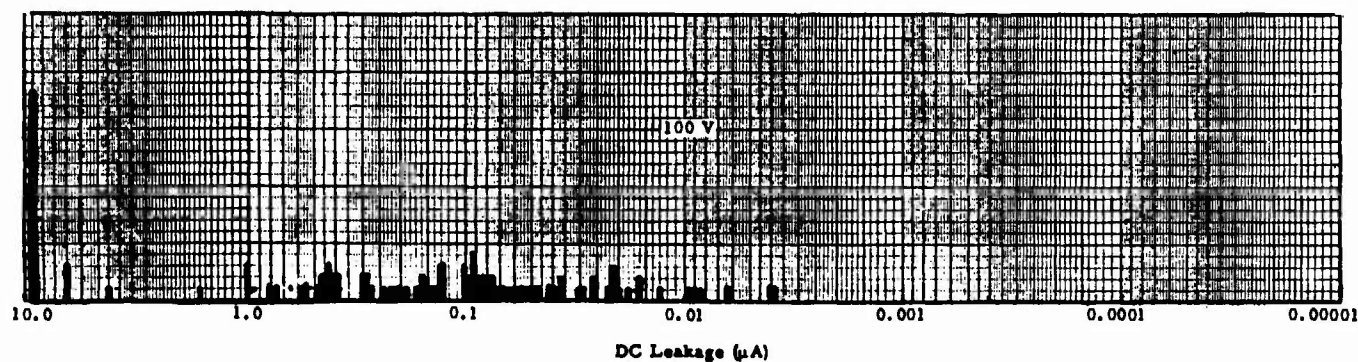
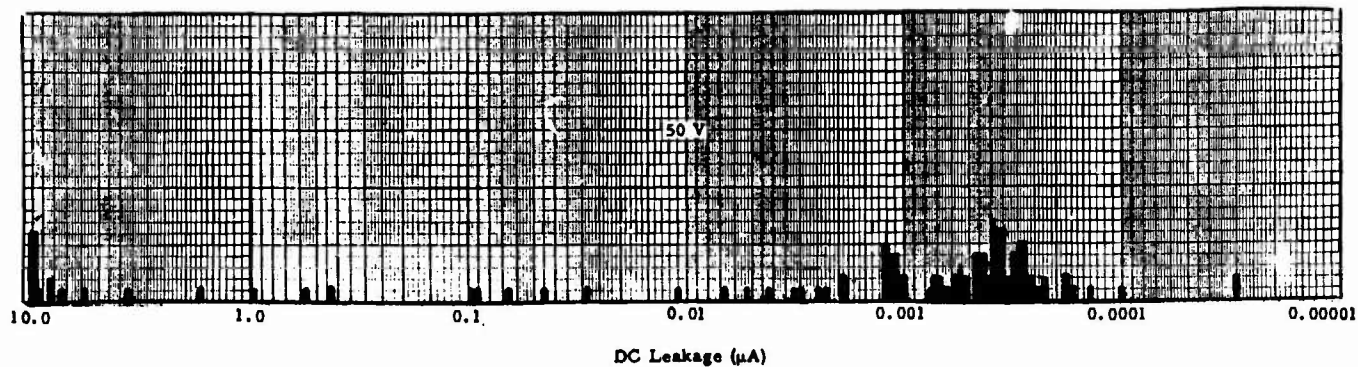
FREQUENCY DISTRIBUTION OF LEAKAGE CURRENT ON 125°C 15,000 HOUR LIFE TEST
FOR 0.01 μF C67 CASE SIZE I MONOLYTHIC CAPACITORS (LOT 6S9205)

Figure 6



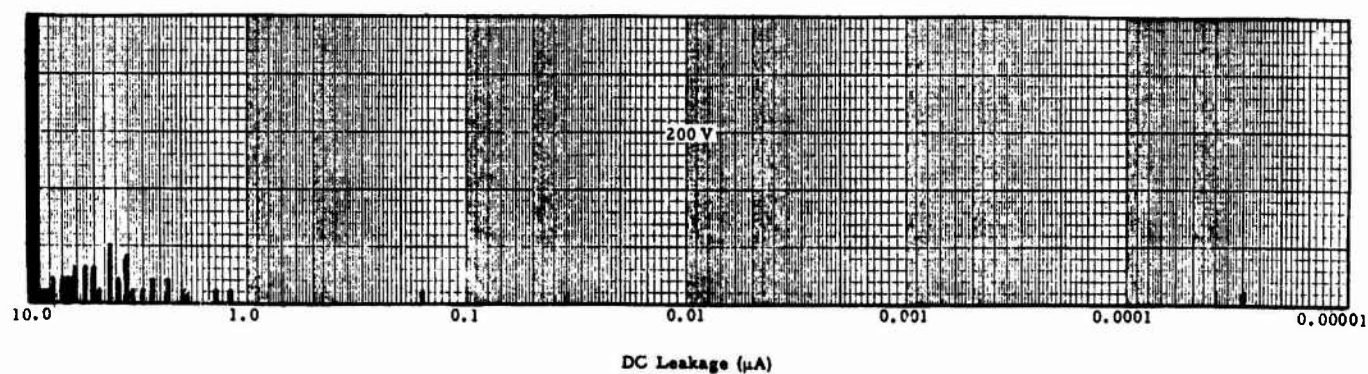
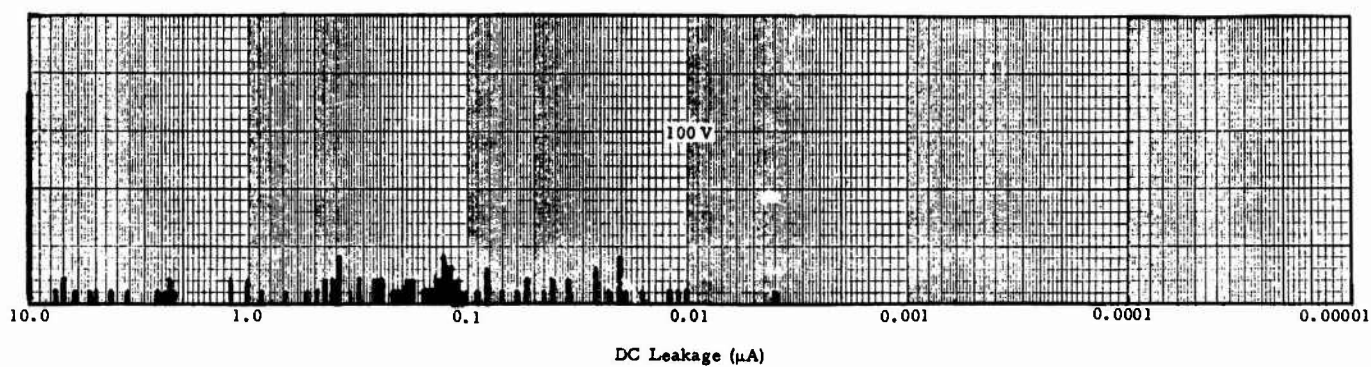
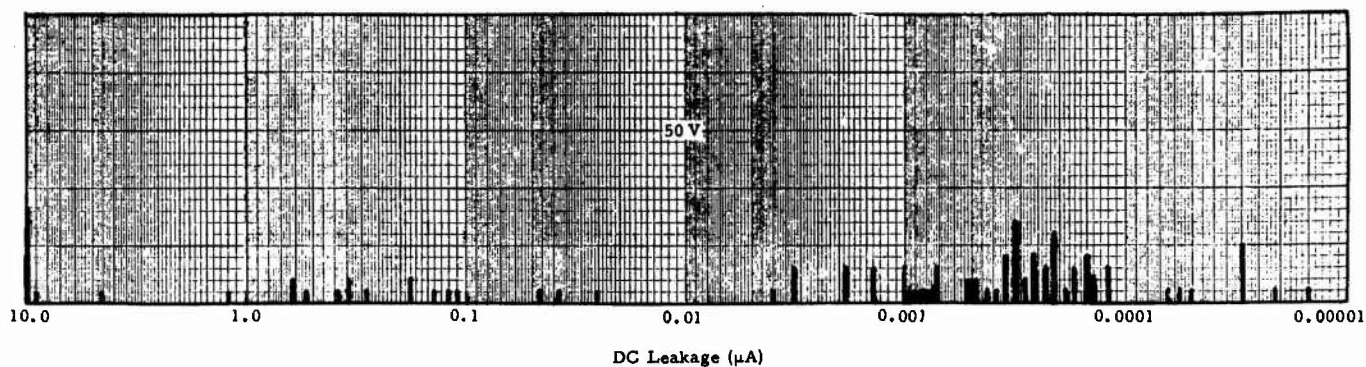
FREQUENCY DISTRIBUTION OF LEAKAGE CURRENT ON 125°C 20,000 HOUR LIFE TEST
FOR 0.01 μF C67 CASE SIZE I MONOLYTHIC CAPACITORS (LOT 659205)

Figure 7



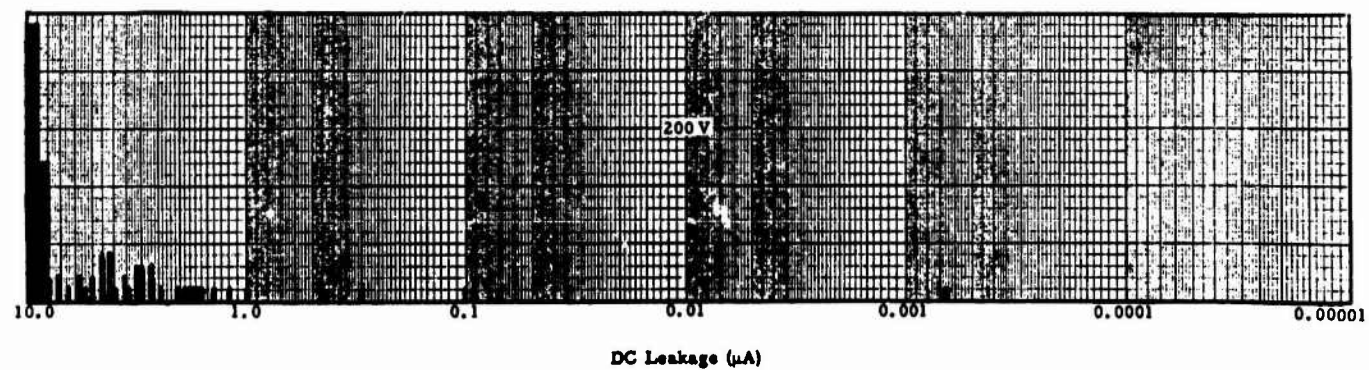
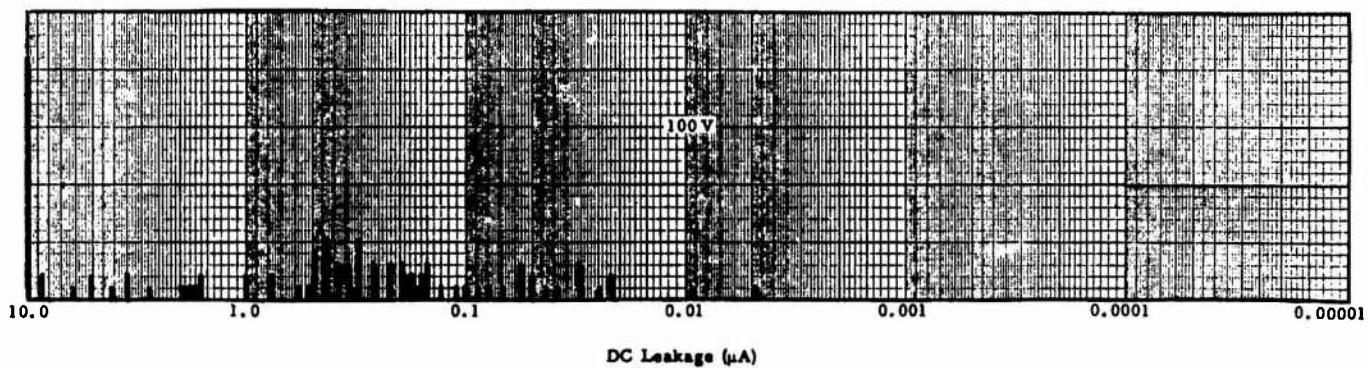
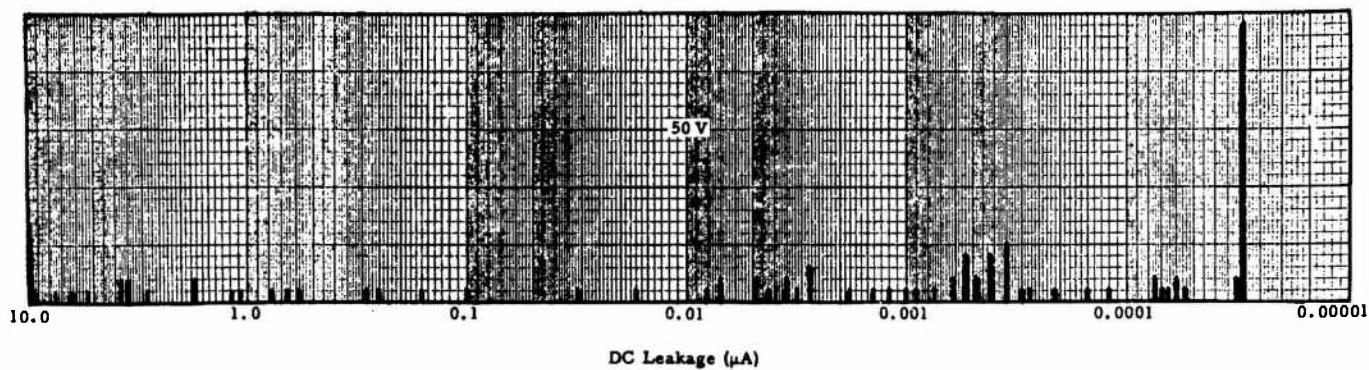
FREQUENCY DISTRIBUTION OF LEAKAGE CURRENT ON 150°C 10,000 HOUR LIFE TEST
FOR 0.01 μF C67 CASE SIZE I MONOLYTHIC CAPACITORS (LOT 659205)

Figure 8



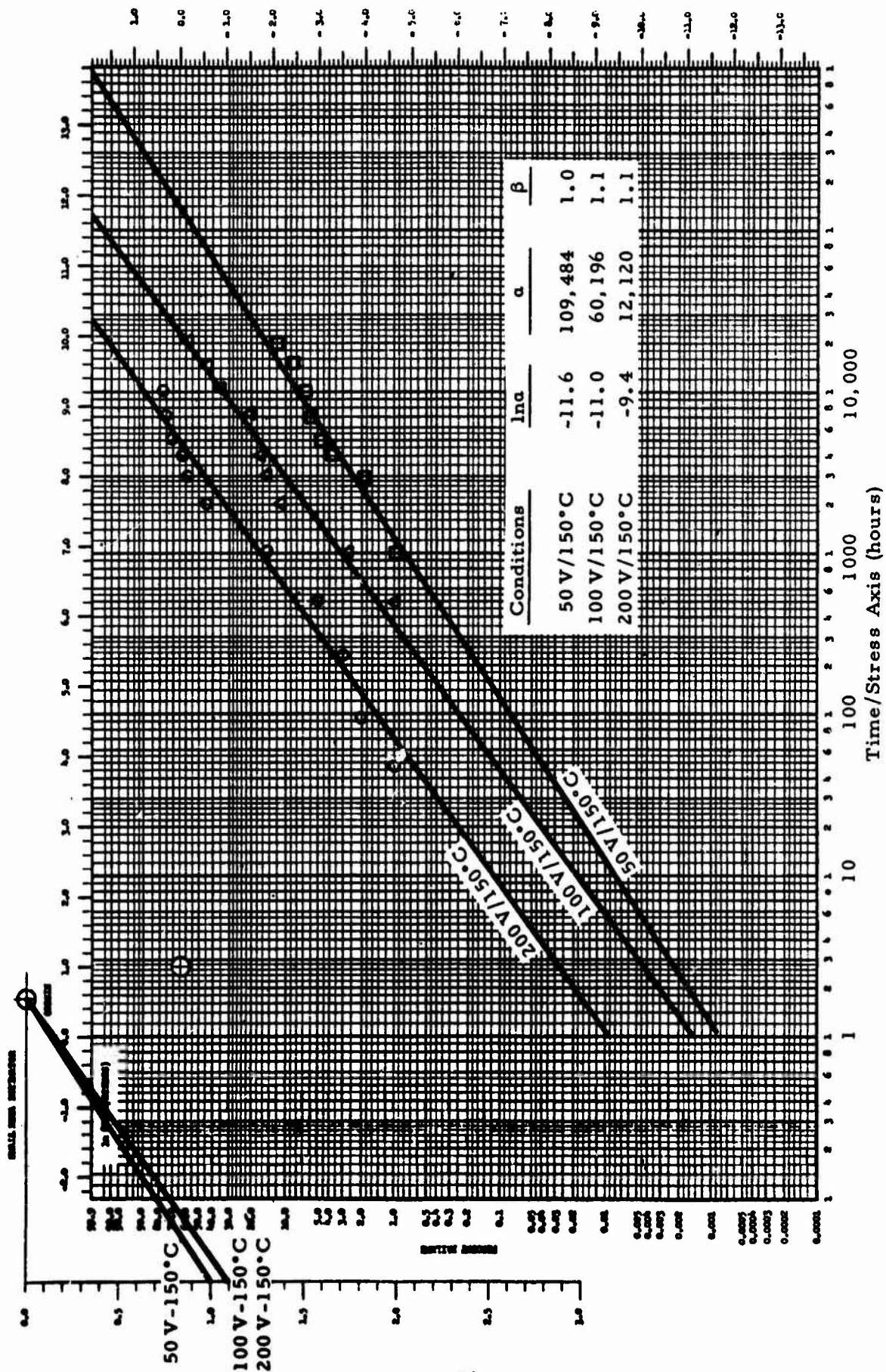
FREQUENCY DISTRIBUTION OF LEAKAGE CURRENT ON 150°C 15,000 HOUR LIFE TEST
FOR 0.01 μF C67 CASE SIZE I MONOLYTHIC CAPACITORS (LOT 6S9205)

Figure 9



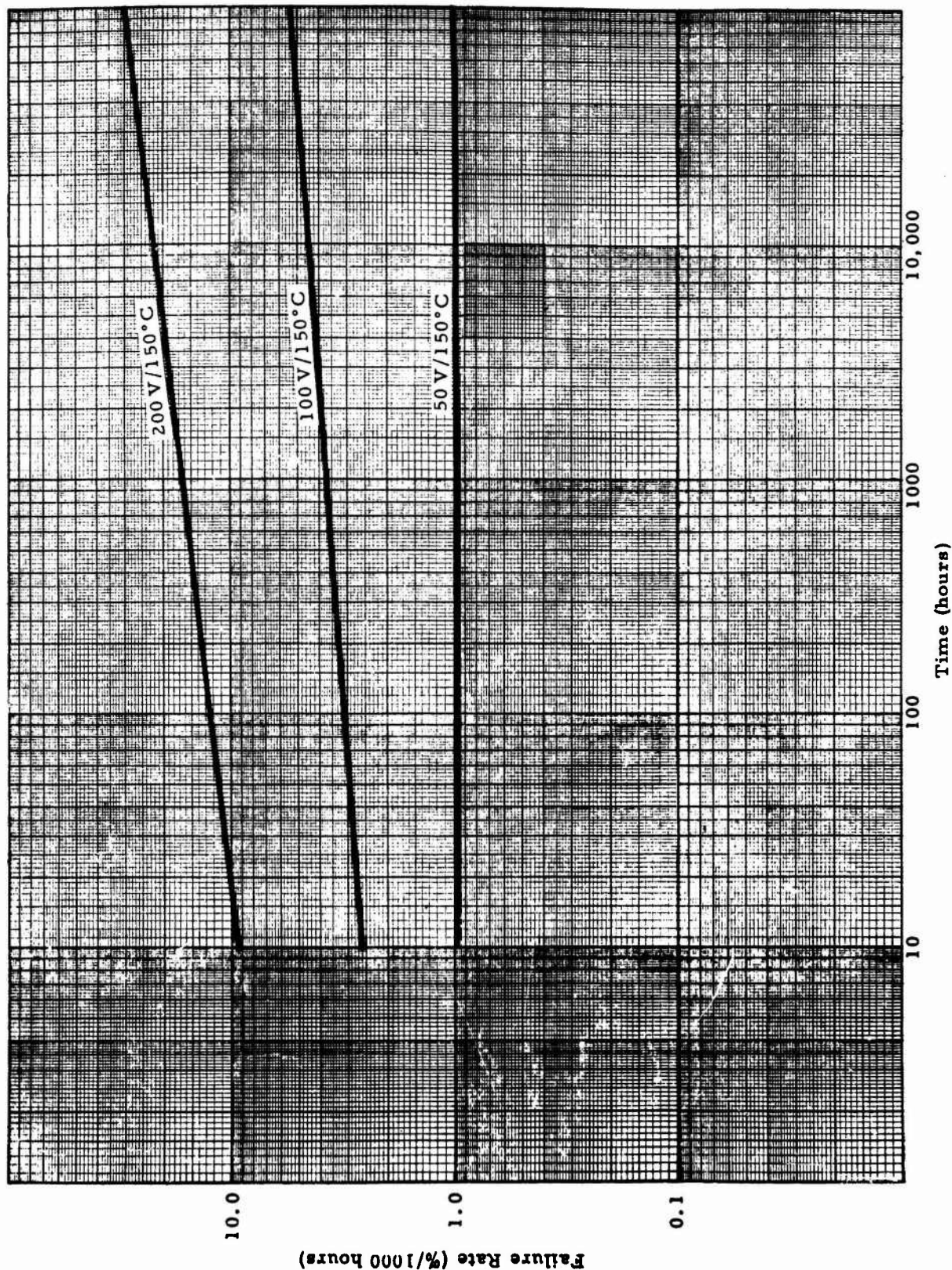
FREQUENCY DISTRIBUTION OF LEAKAGE CURRENT ON 150°C 20,000 HOUR LIFE TEST
FOR 0.01 μF C67 CASE SIZE I MONOLYTHIC CAPACITORS (LOT 689205)

Figure 10



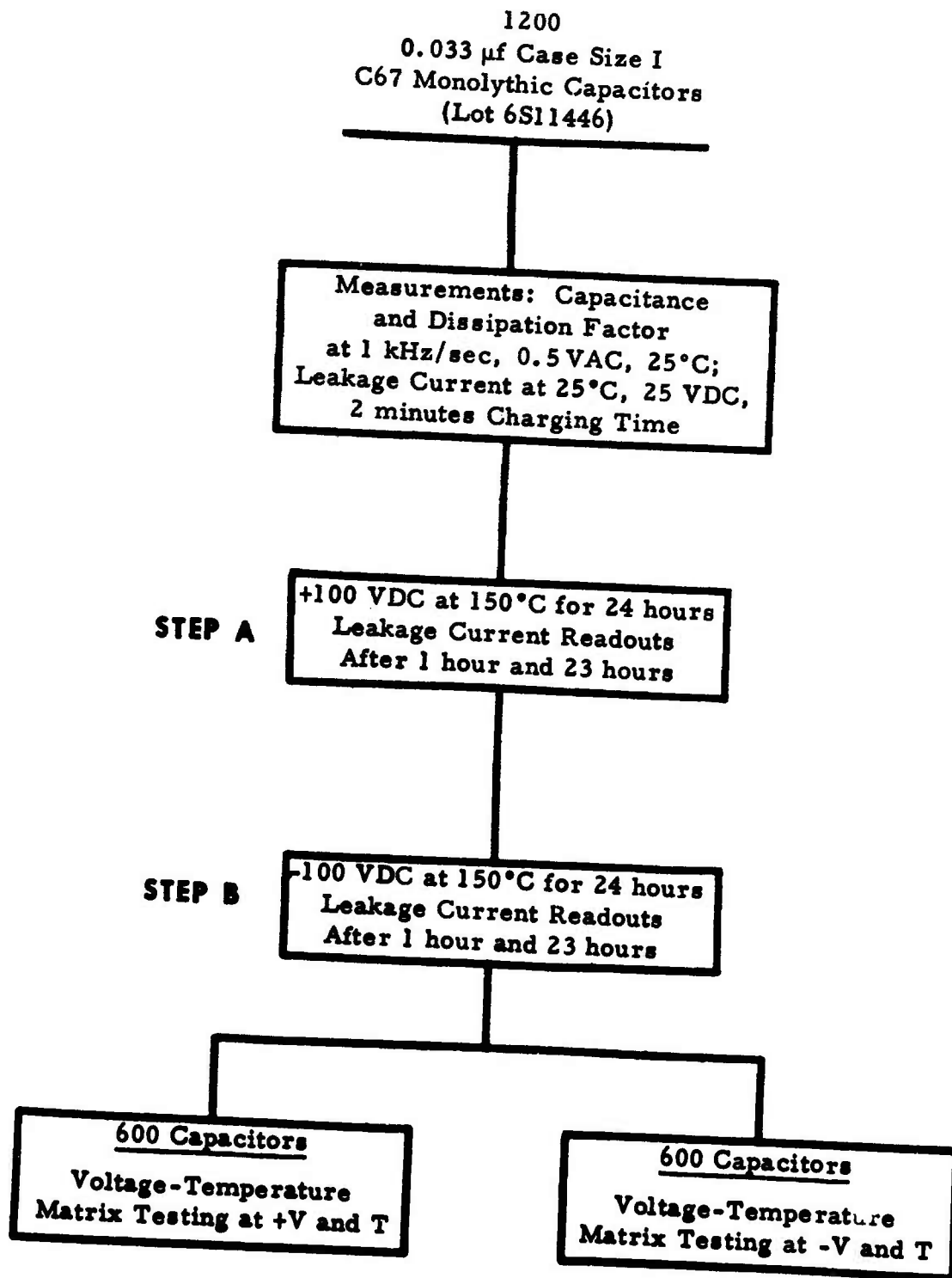
β AND a DETERMINATION CHART

Figure 12



INSTANTANEOUS FAILURE RATES VS TIME

Figure 13



PROPOSED OUTLINE OF SECOND LIFE TEST MATRIX

Figure 14

TABLE I

LIFE TEST MATRIX VOLTAGE/TEMPERATURE CONDITIONS
AND READOUT SCHEDULE FOR 0.01 μ F C67 CASE SIZE I
MONOLYTHIC® CAPACITORS

TEST TEMPERATURE AND NUMBER OF UNITS AT EACH CONDITION

<u>Voltage</u>	<u>85°C</u>	<u>125°C</u>	<u>150°C</u>
25	----	100	-----
50	100	300	100
100	100	100	100
200	100	100	100

LEAKAGE CURRENT READOUTS ARE SCHEDULED AT 1; 48; 96; 240; 504; 1,008;
2,016; 3,024; 4,032; 5,040; 7,056; 10,080; 15,000; 20,000 HOURS and a not yet
designated time towards the end of the contract.

TABLE II

ACTUAL LIFE TEST FAILURES AND
ASSURED LIFE TIMES FOR 0.01 μ F C67
CASE SIZE I MONOLYTHIC® CAPACITORS

<u>Condition Set</u>	<u>Conditions</u>	<u>Number of Failures</u>	<u>Assured Life Time</u>	<u>Earliest Life Test Failure Hour</u>
1	50 V/85°C	0	188,845	-----
2	100 V/85°C	0	29,042	-----
3	200 V/85°C	0	4,475	-----
4	25 V/125°C	0	30,312	-----
5	50 V/125°C	0	10,128	-----
6	100 V/125°C	8	1,557	1008
7	200 V/125°C	5	240	1008
8	50 V/150°C	7	2,110	1008
9	100 V/150°C	38	324	504
0	200 V/150°C	77	50	240

TABLE III
CUMULATIVE PERCENTAGES OF FAILURE
FOR WEIBULL DISTRIBUTION STUDY OF 0.01μF C67 CASE SIZE I
MONOLYTHIC CAPACITORS ON LIFE TEST MATRIX

Hours on Test	Failures in Test Period										Cumulative Failures										Cumulative Percentages of Failures									
	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
240	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
504	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE IV

PROPOSED LIFE TEST MATRIX VOLTAGE/TEMPERATURE CONDITIONS
AND READOUT SCHEDULE FOR 0.033 μ F C67 CASE SIZE 1
MONOLYTHIC® CAPACITORS

TEST TEMPERATURE AND NUMBER OF UNITS AT EACH CONDITION

<u>Voltage</u>	<u>85°C</u>	<u>125°C</u>	<u>150°C</u>
12.5	-----	100	----
25	100	300	100
50	100	100	100
100	100	100	100

LEAKAGE CURRENT READOUTS ARE SCHEDULED AT 24, 96, 240, 504,
1,008, 2,016, 4,032, 7,056, AND 10,080 HOURS.

SECTION 4

PROGRAM FOR NEXT INTERVAL

4.1 0.01 μ F C67 Case Size I MONOLYTHIC® Capacitors

Assured life times (ALT) for each test condition will be calculated using the onset of degradation as a measure of performance time. This tabulation of ALT's will complement that obtained using the failure criteria cited in MIL-C-39014 (See Seventeenth and Eighteenth Interim Progress Reports).

4.2 0.033 μ F C67 Case Size I MONOLYTHIC® Capacitors

- (1) Frequency histograms of leakage current data obtained at selected readout points will be prepared for each life test condition.
- (2) Assured life times will be calculated for each test condition using two measures of performance time: the onset of degradation and the failure criteria cited in MIL-C-39014.
- (3) Best estimate failure rates will be determined by Weibull analysis for test groups providing the necessary quantity and distribution of actual life test failures.
- (4) Tabulations will be made of burn-in failures, actual life test failures and failures predicted by the burn-in failure mode.

SECTION 5

PUBLICATIONS, LECTURES, REPORTS AND CONFERENCES

5.1 Publications

A paper entitled "Concerning the Physics of Failure of Barium Titanate Capacitors" by D. A. Payne was published in the Sixth Annual Reliability Physics Symposium Proceedings, IEEE, New York (1968).

5.2 Reports

The Seventeenth Interim Progress Report, covering the period June 1, 1966 - July 31, 1967 was submitted to, and approved by, the U. S. Army Electronics Command. Distribution of the report was in accordance with USAECOM directives.

A paper entitled "Concerning the Physics of Failure of Barium Titanate Capacitors" by D. A. Payne was presented by F. W. Perry to the Sixth Annual Reliability Physics Symposium held at Los Angeles, California on November 6-8, 1967.

SECTION 6
IDENTIFICATION OF PERSONNEL

The following is a list of the key personnel assigned to this contract and the hours they contributed to the program during this interim:

<u>Personnel</u>	<u>Hours</u>
C. Bailey	9.0
C. Belouin	8.0
B. Cirone	5.0
C. LaCasse	187.0
D. Payne	37.0
H. Tourjee	35.5
A. Vaskas	<u>163.0</u>
TOTAL	444.5

DOCUMENT CONTROL DATA - R&D		
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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY U. S. Army Electronics Command Fort Monmouth, N. J. 07703 AMSEL-KL-EC	
13. ABSTRACT The 20,000 - hour, voltage/temperature life test matrix, which involved the 0.01 μ F C67 Case Size 1 Monolithic capacitor, is discussed. Frequency histograms of all leakage current data and Weibull determinations of failure rates for some of the test conditions are included. In addition, the criteria which determined short-life capacitors during testing are presented, as well as a comparison of calculated assured life times with the times to actual life test failures. Finally, the schedule and conditions for a second voltage/temperature life test matrix using 0.033 μ F C67 device are briefly summarized.		

Security Classification

14. KEY WORDS		LINK A		LINK B		LINK C	
		ROLE	WT	ROLE	WT	ROLE	WT
Capacitors Ceramic Voltage/Temperature Matrix Weibull Determinations of Failure Rate							

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